Naval Surface Warfare Center
Carderock Division
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Analysis of PlugNPlay Software Through Concept Ship Design

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The process of designing a ship concept can be very long and tedious. Calculations, such as vessel bending moments, are often iterated even though the arrangements and loads have changed only slightly. The PlugNPlay software developed in the Center for Innovation in Ship Design was designed to speed up this iteration process. With the ability to view electric loads and other design data, and recalculate analyses such as seakeeping and stability rapidly, PlugNPlay software makes the process faster than calculating conventionally by hand. The PlugNPlay software also brings an interface to Excel and Paramarine for ease in exporting from and importing data to Rhinoceros 3D. This report details how the PlugNPlay software can expedite the extensive calculations needed for a preliminary ship design, and reduce overall design time when moving data between Paramarine and Rhinoceros 3D. To demonstrate this, a ship concept design was created using this software and the design considerations as well as analysis are displayed throughout this paper.

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Abstract

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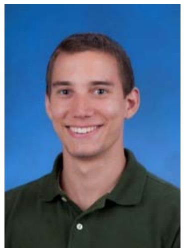
Team

Adam Stickl



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Abbreviations

AAW – Anti-Aircraft Warfare
ASW – Anti-Submarine Warfare
APS – Africa Partnership Station
CB – Center of Buoyancy
CG – Center of Gravity
CISD – Center for Innovation in Ship Design
CIWS – Close-In Weapon System
CO – Commanding Officer
CODAD – Combined Diesel and Diesel
CVLWT – Common Very Lightweight Torpedo
DH – Department Head
DPSS – Design Program for Ship Structures
HVAC – Heating, Ventilation, and Air Conditioning
NSWCCD – Naval Surface Warfare Center Carderock Division
PC-14 – USS Tornado, 14th and last Cyclone Class Patrol Ship
RHIB – Rigid Hull Inflatable Boat
Rhino-Rhinoceros 3D
SS – Sea State
SUW – Surface Warfare
SWBS – Ship Work Breakdown Structure
VERTREP – Vertical Replenishment

Introduction

Objective

The main goal of this project is to test and analyze the PlugNPlay software by creating a patrol craft concept design as a direct example of an end product of the software. Recommendations for the software should be noted for all aspects to ensure ease of future development.

The patrol craft must be suitable for foreign export, producible, maintainable, and easy to operate. The missions this patrol craft will encounter consist of interdiction, coastal patrol, and surveillance.

Background

The PlugNPlay software that is being evaluated was developed by the Center for Innovation in Ship Design (CISD), Naval Surface Warfare Center Carderock Division (NSWCCD). The original concept was laid out by David Widhalm (CISD), and software was written by Max Harper (CISD).

The intent of the software is to ease many calculations in the ship design process. These calculations include, but are not limited to, still water bending moments, intact and damaged stability, seakeeping, electrical loads, weights, and center of gravity. Further development of the software will allow for additional calculations such as powering, maneuvering, lines drawings, and sagging and hogging bending moments. To the user, PlugNPlay is a toolbar that is installed in Rhinoceros 3D (Rhino), with buttons that create various outputs. The design process can be sped up by using a model library, allowing the inputs to the software to come from individual Rhino models that have previously populated properties, such as density, mass, electrical load, and specific fuel consumption. A common model library, shared amongst projects, also provides uniformity between models.

The PlugNPlay software was evaluated by creating a patrol craft concept to meet certain missions and requirements. The patrol craft's purpose is to fulfill all of the missions of the Cyclone class patrol ships of the US Navy. The Africa Partnership Station (APS) and the US are working to provide aid African nations in patrolling their coastal waters and Exclusive Economic Zones to ensure regional and international laws are enforced. A patrol craft that is suitable for foreign export would help fulfill the training and skill building goals established by the APS. Since the US Navy doesn't currently have any active patrol vessels to train the African navies, surface combatants such as frigates and destroyers are used. This is not an efficient use of high value surface combatants. The use of surface combatants is not only more expensive than using

patrol craft, but it is also less affective since most African nations are unlikely to purchase high value surface combatants.

Deliverables

The required deliverables of this project were chosen to ensure a thorough evaluation of the PlugNPlay software and ensure that the concept patrol craft is feasible.

- Weight Summary
- Hull form Lines Drawing
- Intact and Damaged Stability
- Electric Loads Summary
- Speed/Power Curve
- Midship Structural Drawing
- Machinery List
- Schedule
- Summary of Characteristics and Performance
- General Arrangements
- Summary of PlugNPlay's Effects on the Project
- Documented Decision Making Process
- Area/Volume Report
- Seakeeping

Concept Summary

The concept patrol craft that was designed is based off of the Cyclone class patrol vessels in the US Navy. The name of the concept vessel is the PC-R (Patrol Craft Replacement). The PC-R is a solution to the shortage of US Navy offshore patrol vessels and is designed to suit foreign military sales.

Figure 1: PC-R

PlugNPlay

PlugNPlay is a design methodology created at CISD to simplify and speed up the ship concept design process. The methodology is built around a model library that contains major components (engines, generators, weapons, etc.) modeled in Rhino with all pertinent information attached. By combining these components into a single Rhino file, the information is included in the ship design. With all of the information contained in a Rhino model, PlugNPlay is then able to combine Rhino with Paramarine and Excel to run analyses on the design with the ability to quickly interchange or rearrange systems in Rhino and reanalyze.

Overview

PlugNPlay can do many of the required calculations on its own. Below is a diagram that maps the data flow of PlugNPlay. The green squares represent the tools required to use it, and the blue ovals represent the analysis needed for a concept design to be completed. The solid arrows connecting them represent what the PlugNPlay software can do, while the dashed lines represent what needs to be done with other methods.

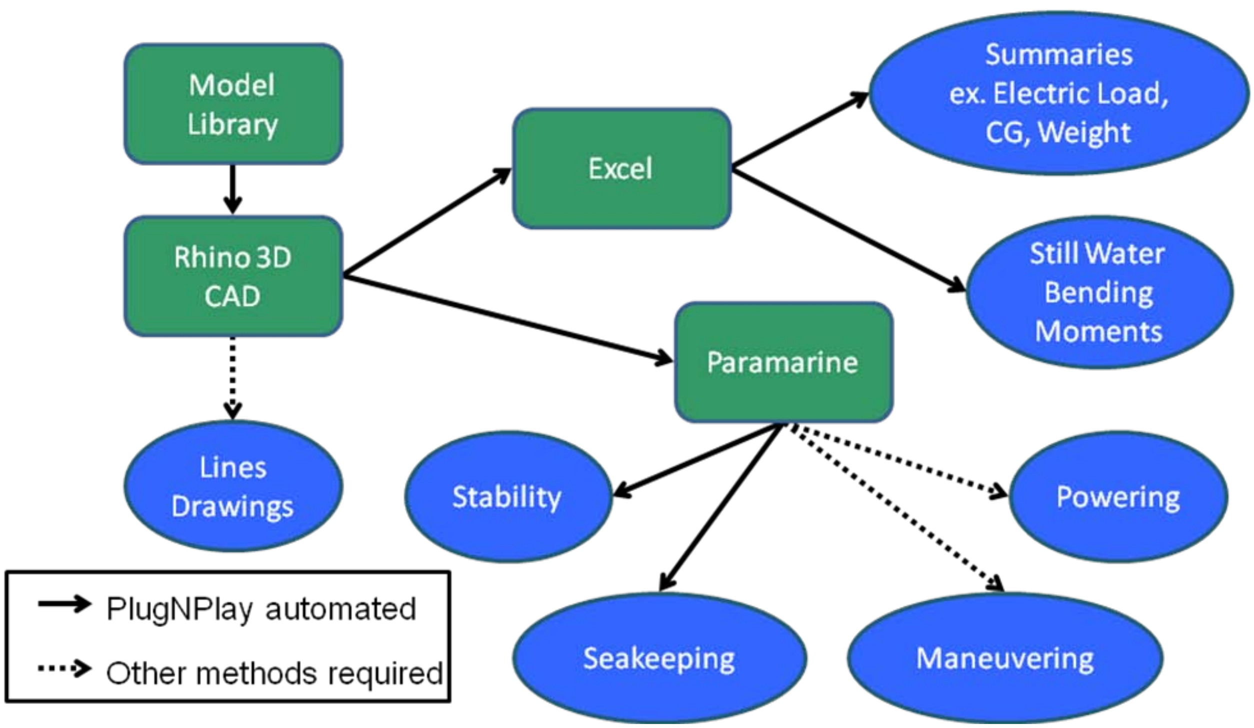


Figure 2: PlugNPlay Data Flow

In a typical design using this method, the model library will contain all of the components with all of their information attached to them. They can then be combined into a single Rhino model, and the other tools come into play. Clicking a button on the PlugNPlay toolbar in Rhino, the

static bending moments and Ship Work Breakdown Structure (SWBS) weight estimate are calculated and displayed in Excel. PlugNPlay also has the ability to convert solid objects representing densities into mass points located at the Center of Gravity (CG) of each object. From that, the software can create a Paramarine model of the ship, saving time and energy. Once in Paramarine, PlugNPlay sets up stability and seakeeping analyses. Maneuvering and powering calculations can be performed as well, but require moderate setup.

Model Library

The model library is a storage space for components to be integrated into ship designs. The more components the better because each component that exists in the model library is potentially one less thing a ship concept design team needs to model.

Each component has information attached to it, so the necessary calculations can be completed. For example the engine shown below has information for fuel type, specific fuel consumption (SFC), weight distribution, and power as shown in Figure 4.

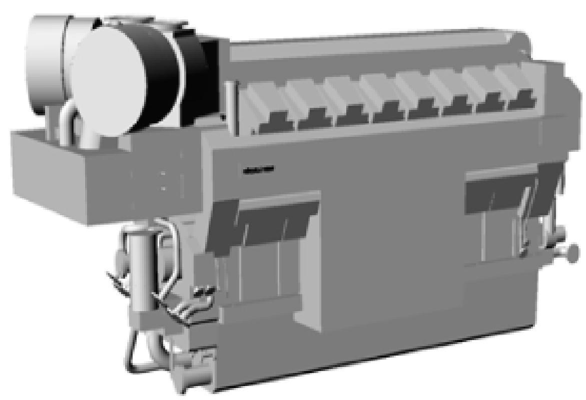


Figure 3: Diesel Engine Model

The information is attached to the model by either a point or 3D solid. In this example, the fuel type, SFC, and power are all represented by points on the object. The name of each respective point is titled after the SWBS number of the object and the value of that property (e.g. 233/4300 for an engine falling into the SWBS 233 group and producing 4,300 kW of power). A component that uses power can have a similar set up, but a negative power value allows the software to compute the difference between power produced and consumed.

To indicate which property a point represents, the points are sorted into layers as shown in Figure 4. The layers in this example that contain information points are labeled “Power (kW)”, “SFC 100% Load (g/kWh)”, and “Fuel Types”. Any property can be stored in the component model by creating a new layer. Layers that do not contain quantitative properties can also be

created. In the engine example, a layer containing a point designating fuel type or solids designating required service space could be added to the model. When multiple components are inserted into the final file, all layers with the same title are automatically combined into a single layer containing all of the related points. This allows the PlugNPlay software to output an Excel spreadsheet with the sum of the power, or any other information broken down by components.

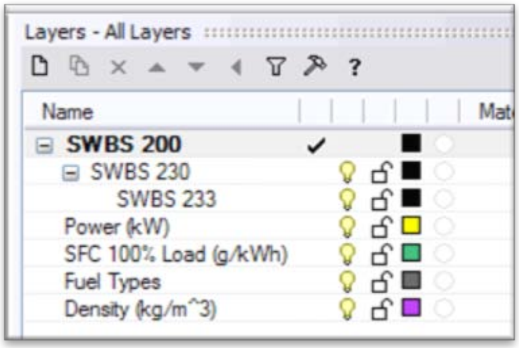


Figure 4: Diesel Engine Layer Breakdown

Density is slightly different, because it is a distributed property and is not represented by a single point. To represent density a solid representative of the component's mass distribution is placed on the density layer. Consider a cube shaped component. A cube on the density layer would represent uniform distribution of mass. However, most components do not have uniform distribution and need to be represented as such. The solid in Figure 5 represents a linear distribution along the y-axis and a uniform distribution along the x-axis for the same cube shaped component. A solid of any shape can be used to represent the mass distribution of a component.

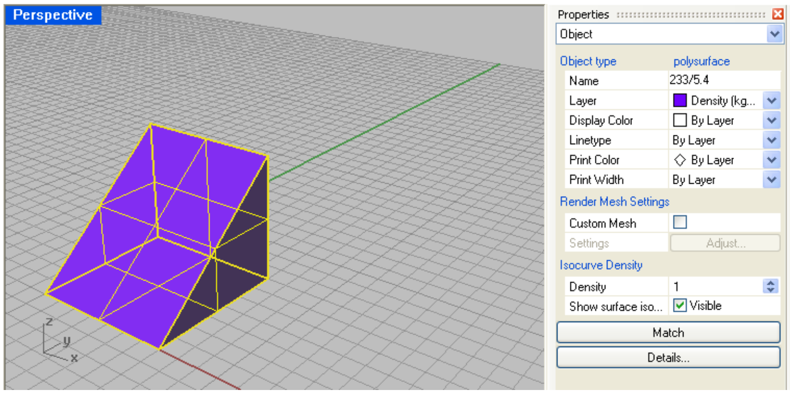


Figure 5: Mass Distribution Model

The value is recorded in the same way as it is for points, by naming the object by SWBS number and quantity as shown in Figure 5. Density in this example is 5.4 kg/m^3 for an engine in SWBS 233 weight group.

The model library is the foundation for a PlugNPlay design. While a well populated model library is of great benefit, it is also possible to develop a model library as a design progresses. Because model library components are simply Rhino models it is easy to create a model library component from an existing 3D model. For the same reason, the model library components can immediately be used in any non-PlugNPlay Rhino model. For the patrol craft designed for the purpose of testing PlugNPlay, the majority of the components were made when needed and were then added to the library for future use.

Analyses

PlugNPlay comes with a tool bar that is imported into Rhino. Bending moments, SWBS weight summaries, electrical summaries, Paramarine models, and center of gravity calculations can be launched by buttons.

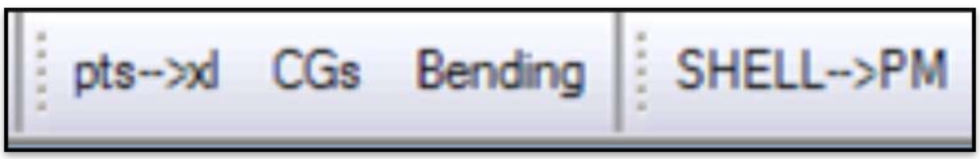


Figure 6: PlugNPlay Toolbar

The “pts→xl” button positioned on the left is used to create a summary of all properties included in the model. The “CGs” button calculates the center of gravity of each component using its density solid and creates a mass point there. The “Bending” button is used to calculate the bending moments and creates a file in Excel to display them. The button called “SHELL→PM” creates and opens a Paramarine model of the hullform configured for stability and seakeeping analyses.

Summary of Properties

The PlugNPlay toolbar can be used to output a summary of properties to Excel. The components are grouped by SWBS and then placed in a table. Each SWBS group is given a row and each property (e.g. mass, power, etc.) is given a column. Table 1 shows the SWBS 200 level breakdown of the patrol craft designed.

		Count	CG x	CG y	CG z	Mass (kg)	Power (kW)	SFC 100% Load (g/kWh)
SWBS 200	**PROPULSION PLANT**	**14**	**20.61**	**0.06**	**1.97**	**67862.29**	**8600.00**	**440.00**
233	DIESEL ENGINES	4	22.78	-0.07	2.01	25304.05	8600.00	440.00
240	TRANSMISSION + PROPULSOR SYSTEMS	1	11.35	0.00	2.06	12593.75		
241	REDUCTION GEARS	2	16.75	-0.01	1.56	5350.74		
243	SHAFTING	2	20.55	0.81	1.77	7040.33		
245	PROPULSORS	2	2.63	0.00	-0.17	31.14		
250	SUPPORT SYSTEMS	1	14.16	0.00	2.06	6886.47		
260	PROPUL SUP SYS- FUEL, LUBE OIL	1	33.63	0.00	2.06	6358.08		
290	SPECIAL PURPOSE SYSTEMS	1	31.20	0.00	2.06	4297.73		
	Cumulative		**25.71**	**-0.01**	**2.74**	**521801.59**	**9082.00**	

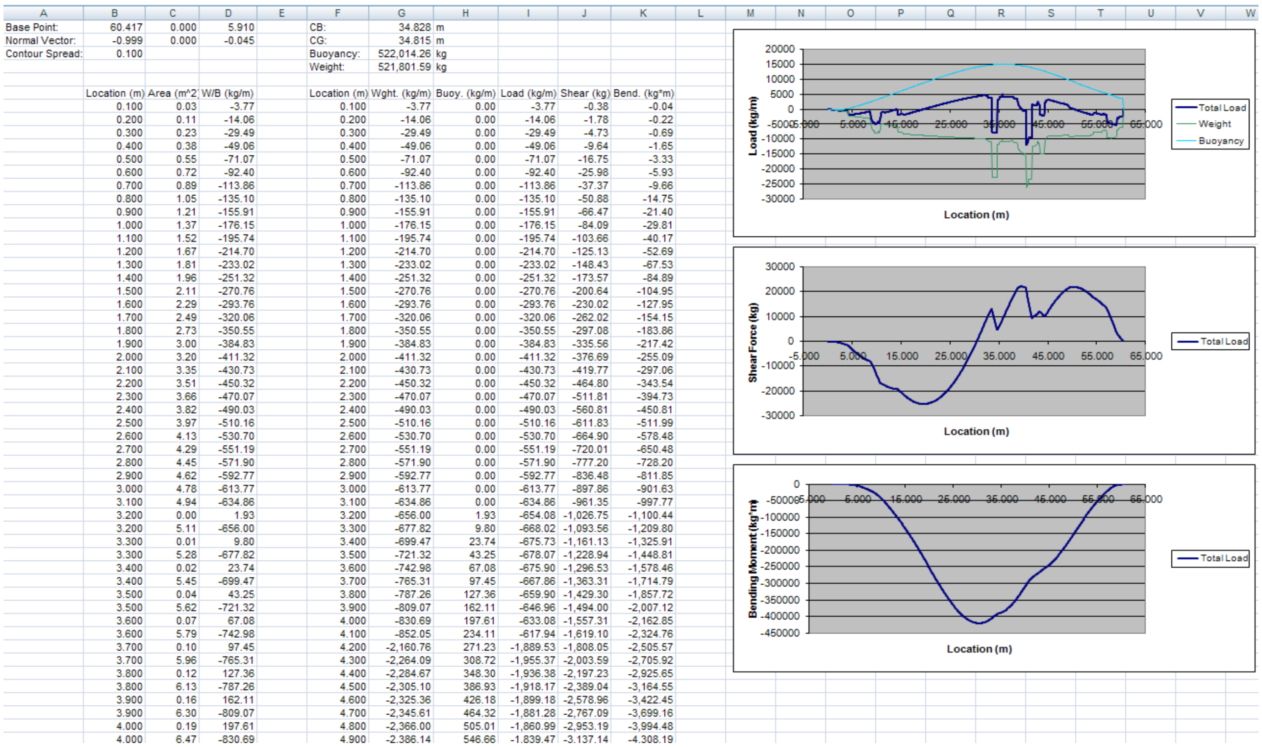
Table 1: SWBS Breakdown

In addition to the properties found in the model, PlugNPlay adds columns to represent the CG of each SWBS group. PlugNPlay is able to calculate this CG from the masses and their locations in Rhino. The bolded SWBS 200 line shows the total for this SWBS group. There is also a cumulative row at the bottom that contains totals for the entire design, including components not shown in the table.

The Excel file created by PlugNPlay also has a tab that breaks it down further by individual item. Therefore, each diesel engine is shown separately, to allow items within the same three digit SWBS group that have different values to be viewed. For example, each individual diesel engine would have its own row instead of being combined into the SWBS 233 row.

Bending Moments

The PlugNPlay toolbar can be used to calculate still water bending moments. PlugNPlay uses the density solids, mass points, and hull to calculate the weight and buoyancy distributions along the length of the design given the specified waterplane. The calculated data and graphs of weight and buoyancy distributions, shear forces, and bending moments are output to Excel. PlugNPlay makes it simple to then go back and adjust objects on the ship, if necessary, and recalculate the moments within minutes, greatly cutting down the amount of time to work multiple iterations. A sample bending moments output is shown in Figure 7. Values are given for weight, buoyancy, load, shear force, and bending moment at each contour; graphs are also generated.



A	B	C	D	E	F	G	H	I	J	K
Base Point:	60.417	0.000	5.910		CB:	34.828	m			
Normal Vector:	-0.999	0.000	-0.045		CG:	34.815	m			
Contour Spread:	0.100				Buoyancy:	522,014.26	kg			
					Weight:	521,801.59	kg			
	Location (m)	Area (m^2)	W/B (kg/m)		Location (m)	Wght. (kg/m)	Buoy. (kg/m)	Load (kg/m)	Shear (kg)	Bend. (kg*m)
	0.100	0.03	-3.77		0.100	-3.77	0.00	-3.77	-0.38	-0.04
	0.200	0.11	-14.06		0.200	-14.06	0.00	-14.06	-1.78	-0.22
	0.300	0.23	-29.49		0.300	-29.49	0.00	-29.49	-4.73	-0.69
	0.400	0.38	-49.06		0.400	-49.06	0.00	-49.06	-9.64	-1.65
	0.500	0.55	-71.07		0.500	-71.07	0.00	-71.07	-16.75	-3.33
	0.600	0.72	-92.40		0.600	-92.40	0.00	-92.40	-25.98	-5.93
	0.700	0.89	-113.86		0.700	-113.86	0.00	-113.86	-37.37	-9.66
	0.800	1.05	-135.10		0.800	-135.10	0.00	-135.10	-50.88	-14.75
	0.900	1.21	-155.91		0.900	-155.91	0.00	-155.91	-66.47	-21.40
	1.000	1.37	-176.15		1.000	-176.15	0.00	-176.15	-84.09	-29.81
	1.100	1.52	-195.74		1.100	-195.74	0.00	-195.74	-103.66	-40.17
	1.200	1.67	-214.70		1.200	-214.70	0.00	-214.70	-125.13	-52.69
	1.300	1.81	-233.02		1.300	-233.02	0.00	-233.02	-148.43	-67.53
	1.400	1.96	-251.32		1.400	-251.32	0.00	-251.32	-173.57	-84.89
	1.500	2.11	-270.76		1.500	-270.76	0.00	-270.76	-200.64	-104.95
	1.600	2.29	-293.76		1.600	-293.76	0.00	-293.76	-230.02	-127.95
	1.700	2.49	-320.06		1.700	-320.06	0.00	-320.06	-262.02	-154.15
	1.800	2.73	-350.55		1.800	-350.55	0.00	-350.55	-297.08	-183.86
	1.900	3.00	-384.83		1.900	-384.83	0.00	-384.83	-335.56	-217.42
	2.000	3.20	-411.32		2.000	-411.32	0.00	-411.32	-376.69	-255.09
	2.100	3.35	-430.73		2.100	-430.73	0.00	-430.73	-419.77	-297.06
	2.200	3.51	-450.32		2.200	-450.32	0.00	-450.32	-464.80	-343.54
	2.300	3.66	-470.07		2.300	-470.07	0.00	-470.07	-511.81	-394.73
	2.400	3.82	-490.03		2.400	-490.03	0.00	-490.03	-560.81	-450.81
	2.500	3.97	-510.16		2.500	-510.16	0.00	-510.16	-611.83	-511.99
	2.600	4.13	-530.70		2.600	-530.70	0.00	-530.70	-664.90	-578.48
	2.700	4.29	-551.19		2.700	-551.19	0.00	-551.19	-720.01	-650.48
	2.800	4.45	-571.90		2.800	-571.90	0.00	-571.90	-777.20	-728.20
	2.900	4.62	-592.77		2.900	-592.77	0.00	-592.77	-836.48	-811.85
	3.000	4.78	-613.77		3.000	-613.77	0.00	-613.77	-897.86	-901.63
	3.100	4.94	-634.86		3.100	-634.86	0.00	-634.86	-961.35	-997.77
	3.200	0.00	1.93		3.200	-656.00	1.93	-654.08	-1,026.75	-1,100.44
	3.200	5.11	-656.00		3.300	-677.82	9.80	-668.02	-1,093.56	-1,209.80
	3.300	0.01	9.80		3.400	-699.47	23.74	-675.73	-1,161.13	-1,325.91
	3.300	5.28	-677.82		3.500	-721.32	43.25	-678.07	-1,228.94	-1,448.81
	3.400	0.02	23.74		3.600	-742.98	67.08	-675.90	-1,296.53	-1,578.46
	3.400	5.45	-699.47		3.700	-765.31	97.45	-667.86	-1,363.31	-1,714.79
	3.500	0.04	43.25		3.800	-787.26	127.36	-659.90	-1,429.30	-1,857.72
	3.500	5.62	-721.32		3.900	-809.07	162.11	-646.96	-1,494.00	-2,007.12
	3.600	0.07	67.08		4.000	-830.69	197.61	-633.08	-1,557.31	-2,162.85
	3.600	5.79	-742.98		4.100	-852.05	234.11	-617.94	-1,619.10	-2,324.76
	3.700	0.10	97.45		4.200	-2,160.76	271.23	-1,889.53	-1,808.05	-2,505.57
	3.700	5.96	-765.31		4.300	-2,264.09	308.72	-1,955.37	-2,003.59	-2,705.92
	3.800	0.12	127.36		4.400	-2,284.67	348.30	-1,936.38	-2,197.23	-2,925.65
	3.800	6.13	-787.26		4.500	-2,305.10	386.93	-1,918.17	-2,389.04	-3,164.55
	3.900	0.16	162.11		4.600	-2,325.36	426.18	-1,899.18	-2,578.96	-3,422.45
	3.900	6.30	-809.07		4.700	-2,345.61	464.32	-1,881.28	-2,767.09	-3,699.16
	4.000	0.19	197.61		4.800	-2,366.00	505.01	-1,860.99	-2,953.19	-3,994.48
	4.000	6.47	-830.69		4.900	-2,386.14	546.66	-1,839.47	-3,137.14	-4,308.19

Figure 7: Bending Moment Output

Seakeeping and Stability

The PlugNPlay toolbar can be used to export the Rhino model of the hull with all of its associated mass points into Paramarine. When PlugNPlay imports the model into Paramarine it sets up stability and seakeeping analyses. There are a few inputs that Paramarine still requires, but, within minutes, the stability and seakeeping calculations can be run, again with the ability to go back and make changes to the model in Rhino and reanalyze in a relatively short amount of time.

Powering and Maneuvering

Unlike with stability and seakeeping, PlugNPlay does not set up the powering or maneuvering analyses. However, powering and maneuvering analyses can be set up and run in Paramarine. Because PlugNPlay is capable of creating a Paramarine model, any analysis capability that exists in Paramarine can be run on a PlugNPlay model.

Lines Drawings

The lines drawings are another set of outputs that need to be created outside PlugNPlay. Once the model is created in Rhino though, the drawings are created as they would be for any other ship design.

Patrol Craft

Mission

The goal of the patrol craft design was to determine the utility of the PlugNPlay design software and draw recommendations for improvement. The patrol craft was designed to perform a mission and fulfill a set of requirements.

The mission of this patrol craft is to conduct coastal patrol, surveillance, interdiction, and provide a forward presence. In the past, the US Navy has sent frigates and destroyers to help allied foreign nations patrol their own waters as part of the APS. Designing a smaller vessel would allow the US to accomplish this at less expense and would provide a vessel to sell or supply to foreign navies. Thus, an important aspect of the PC-R design is producibility.

Requirements

Threshold and objective requirements were set during the preliminary stages of the project. The requirements are loosely based off the PC-14. The requirements include weapon systems for anti-surface, anti-air, and anti-submarine warfare. A complete list of threshold and objective requirements are shown in Table 2.

PC-R Specifications		
	Threshold	**Objective**
Range	2,000 nm	3,500 nm
Max Speed	24 kts	36 kts
Flight Deck	none	VERTREP
Boat Handling	7 m RHIB equivalent L&R	11 m RHIB equivalent L&R w/ support facility
AAW	Stinger Missile	CIWS & MK 41 Self Defense Launching System
ASW	none	hull mounted sonar, towed array, & Common Very Light-Weight Torpedoes
SUW	40 mm main gun	76 mm main gun, 8 Stand-Off Land Attack Missiles
Sea State Operability	SS3	SS4
Sea State Survivability	SS5	SS6
Berthing	25	45
Displacement	250-700 tons	

Table 2: PC-R Requirements

Hull Form Selection

Three hullforms were given consideration before the decision was made to use a semi-displacement hull form. The two other hullforms were an axe hull and a planing hull.

The axe hull, seen in Figure 8, has benefits that include reduced slamming, wavemaking resistance, and spray. The hullform requires a long waterline for the amount of volume in the ship. The narrow beam and limited deck area severely limit the number of objective requirements that can be achieved using this hullform.

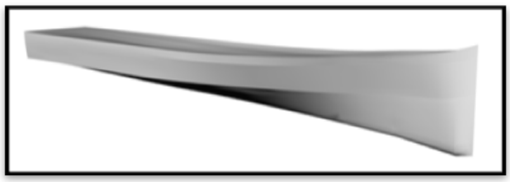


Figure 8: Axe Hull

The planing hull considered, seen in Figure 9, was based on a NATO Patrol Boat. A benefit of a planing hull is low resistance at planing speeds, although the resistance at pre-planing speeds is larger than a displacement hullform. Even if the objective speed requirement was met, the ship would not be able to take advantage of a planing hullform. Furthermore, the PlugNPlay Rhino model was utilized to determine that the machinery required to power the design was not arrangeable in the scaled NATO hullform.

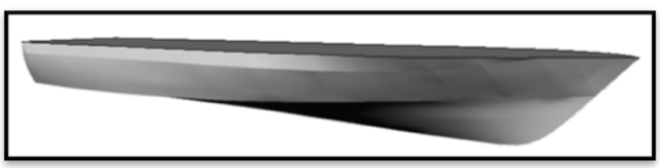


Figure 9: Planing Hull

Finally, the semi-displacement hull form, seen in Figure 10, was considered and selected for use. Semi-displacement hulls have a lower slow speed resistance than a planing hull and are suitable for the speed and displacement ranges indicated by the requirements. The straight edges incorporated into the hull make it cheaper and easier to produce which is an added benefit for foreign military sales. The semi-displacement hull chosen is based off of the PCG 612 and scaled down to 198 feet, and is used for the final design.

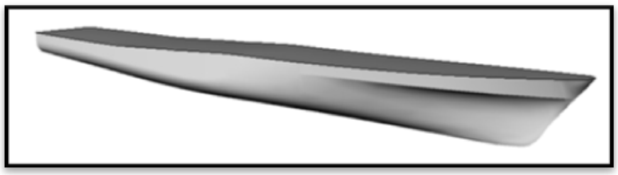


Figure 10: Semi-Displacement Hull

Principal Characteristics

One of the main factors in sizing the ship was the deck space needed to mount the weapon systems, launch a RHIB, and support VERTREP. Another driving factor was the amount of berthing needed for the personnel required to operate these systems. The final length was 197.7 feet, with a beam of 26.7 feet and enough berthing for 40. The propulsion system selected allows it to reach a trial speed of 32 knots at full load and have a range of 3,500 nm at 12 knots at full load.

Displacement (LT)	496
Length (ft)	197.7
Beam (ft)	26.7
Draft (ft)	6.5
Trial Speed (kts)	32
Range (nm) at 12 kts	3,500
Berthing	40

Table 3: Principal Characteristics

Resistance

The resistance from the PCG 612 model tests was used to predict the resistance for the PC-R. Figure 11 shows the estimated power curve that was created from the resistance data. Just over 6,000 horsepower was required to reach the threshold speed of 25 knots. About 11,500 horsepower results in the trial speed of 32 knots.

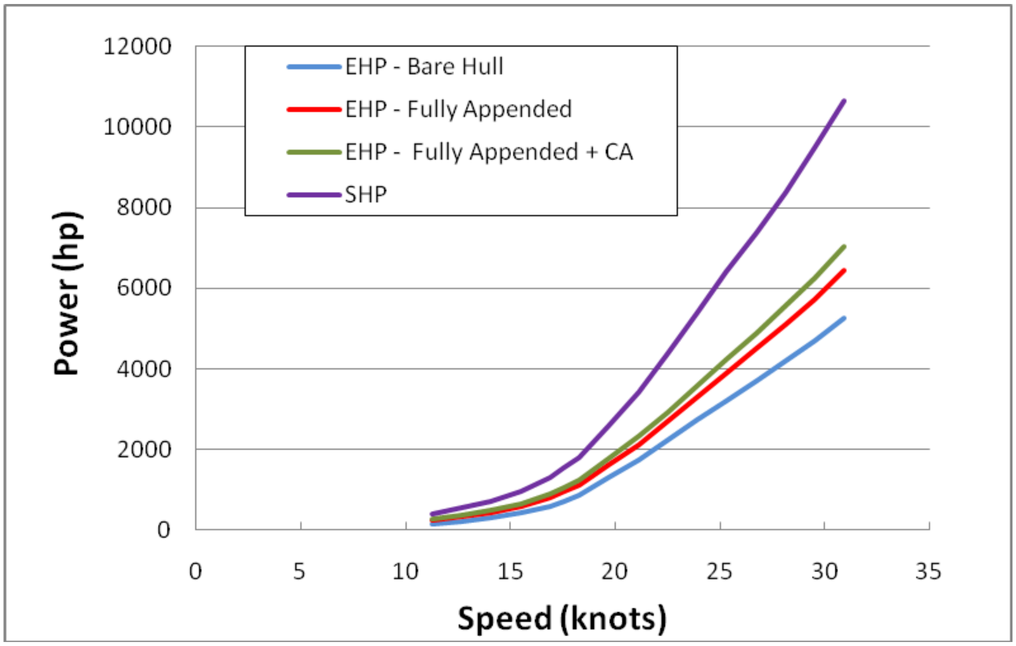


Figure 11: Power Curve

Propulsion

A major factor in choosing the propulsion system was that the PC-R must be suitable for foreign export.

First, a gas turbine was considered with water jets, but with missions requiring slow patrol speeds, water jets would be inefficient. Gas turbines have a higher power density than diesel engines; however gas turbines require more maintenance, are expensive, and have higher fuel consumption. Additionally, for a patrol craft with a range of 3,500 nautical miles, some form of redundancy in propulsion is highly valued. For these reasons, the gas turbine and water jet scheme was ruled out for the PC-R.

The second propulsion method considered was two diesel engines sharing a common gearbox with two output shafts leading to fixed propellers. The reasoning behind not using the traditional combined diesel and diesel (CODAD) powering system, which has only one shaft, is due to the desire to have two output shafts. The advantages of this configuration are the increased

redundancy and the decreased propeller diameter two shafts provide versus one shaft. However, there is no existing gearbox designed for two diesels and two output shafts that would satisfy the requirements of the PC-R. A patrol craft requiring a unique and new gearbox would likely be less producible and of unknown reliability. This assessed high risk led to the decision not to use the altered CODAD design for the PC-R.

The propulsion design chosen for the PC-R was two diesel engines, each linked to its own reduction gear. This adds redundancy and the PC-R will still be able to perform at its endurance speed if one engine, gearbox, shaft, or propeller becomes inoperable. The gearboxes that were chosen are made by ZF (23560C) and are designed to work with the MTU 20V4000M93L high-speed diesel engines (4,300 kW per engine) that were chosen for the PC-R. At first, larger medium speed diesels were considered to ensure longevity and easier maintenance. After using PlugNPlay to analyze the machinery arrangements and the longitudinal loading, the choice for more compact and lighter high speed diesels was made.

Figure 12: MTU 20V4000M93L

Figure 13: ZF 23560C Gearbox

With the selected machinery configuration, the PC-R easily meets the threshold requirement for speed but falls short of the objective speed of 36 knots. The gearbox can be disengaged from the propeller shaft allowing the propeller and shaft to freely spin to reduce the drag as the ship moves. This is particularly important when one diesel is down; the PC-R can travel to port at endurance speed (12 knots) on the remaining diesel. The gearbox chosen is also reversible, allowing for fixed pitch propellers, similar to the PC-14 design. The propeller was designed at the Naval Surface Warfare Center Carderock Division (NSWCCD). It has 6 blades with a pitch ratio of 1.465 at 0.7 m radius. The selected propulsion system contributes to the redundancy, producibility, and maintainability of the PC-R.

Powering and Machinery

A summary of the selected machinery is given in Table 4. As mentioned in the Propulsion section, the two diesels provide 8,600 kW of power.

	Manufacturer	**Model**	**Quantity**
Engine:	MTU	20V4000M93L	2
Gearbox:	ZF	23560C	2
Genset:	Armstrong	A250CU	2
Propellers:	NSWCCD PC-14	NSWCCD PC-14	2

Table 4: Machinery List

The electrical load estimate was based on a previous patrol vessel in the Cyclone class, PC-14. Most of the electric loads, such as those for combat systems and communication systems, were assumed to be the same as those on the PC-14. This assumption was augmented by electric loads data provided by the PlugNPlay summary of properties which included system specific loads for the PC-R. It was determined that the Heating, Ventilation, and Air Conditioning (HVAC) load would need to be volumetrically scaled.

The PC-14 originally had about 68 kW dedicated to the HVAC load. This represents the worst case scenario in the winter season. The PC-14 HVAC load was volumetrically scaled to estimate the PC-R worst case HVAC load of 116 kW. The PC-14 had a total electrical load of 146 kW. The estimated difference in HVAC load between the PC-R and the PC-14 was added to the total electric load of the PC-14 resulting in a total electric load estimate for the PC-R of 194 kW. Table 5 provides more details on this calculation. PlugNPlay made this process easier by providing the PC-R's known loads, an accounting system, and load summary. The model library does not include electrical load data for every component modeled. To evaluate the software's ability to summarize the electrical load data, values were inserted into the models of systems on the PC-R. This way, the Excel spreadsheet summary included electrical load data. This electric load data was saved back to the model library so future PlugNPlay models will have that data.

HVAC	H/AC Names	Values (kW)
	A/H UNIT (GALLEY & MESS)	5.25
	A/H UNIT (PILOTHOUSE)	11.34
	A/H UNIT (FWD QTRS)	5.25
	A/H UNIT (CIC & CRYPTO)	3.5
	A/H UNIT (CO & OFF QTRS)	5.25
	A/C UNIT (EOS)	0.25
	20 TON A/C COMP CONT	0.14
	GENERATOR SPACE HEATER #1	0.25
	A/H (SEAL QTRS)	5.25
	AUX MACHY SP #3 A/H UNIT	5.25
	SEALS QUARTERS PREHEATER	2.2
	7.5 TON A/C COMPRESSOR	7.56
	PC-14 Total:	51.49
	PC-14 Total * Volumetric Scale Factor (SF)	87.87
	(PC-14 Total * SF) + 20% Margin	105
	(PC-14 Total * SF) + 20% Margin + 10% Service Life Allowance (SLA)	116

PC-14 HVAC (kW) with Margin and SLA	PC-R HVAC (kW) with Margin and SLA	Difference: (kW)
68	116	48

PC-14 Load (kW)	HVAC Load Difference (kW)	**PC-R Load (kW)**
146	48	**194**

Table 5: Electric Loads

Weights

The weight summary for the PC-R was created using PlugNPlay. Every component's weight was added under their respective SWBS group. For components with inexact weights (paint, accommodations, etc.), a regression analysis tool was used with data from PC-14 and the PCG 612 to approximate the weight. These estimates were placed into the PlugNPlay model as density solids so the weights could be positioned in the general arrangements, thus giving as accurate trim and bending moments as possible with the data on hand. For example, the structural weight was distributed as the shape of the actual hull and superstructure. PlugNPlay was then used to export the SWBS summary into Excel and the group totals were entered in the table below. The full SWBS summary as outputted by PlugNPlay can be seen in Appendix A.

Lightship displacement for the PC-R was calculated at 384 LT. The margin used was ten percent and, after adding deadweight, the total displacement was estimated at 496 LT. The breakdown is shown in the table below.

SWBS Group	Weight (LT)
100	173
200	67
300	21
400	21
500	50
600	36
700	16
Lightship	384
Lightship + Margin (10%)	422
Deadweight	74
Total	496

Table 6: Weight Summary

Bending Moments

The still water bending moments were calculated by PlugNPlay. Currently, PlugNPlay is not capable of calculating wave induced hogging and sagging moments. For the still water bending moments, a waterplane at the draft of the ship was inserted, and PlugNPlay output the moments. The maximum moment was found to be 1,380 LT-ft. Several iterations were completed concurrently with the general arrangements before arriving at this final value. The first iteration showed a large moment near midships due to weapon systems and engines located close together. After re-arranging those components, the maximum moment decreased. Arrangements were refined until the moment was minimized.

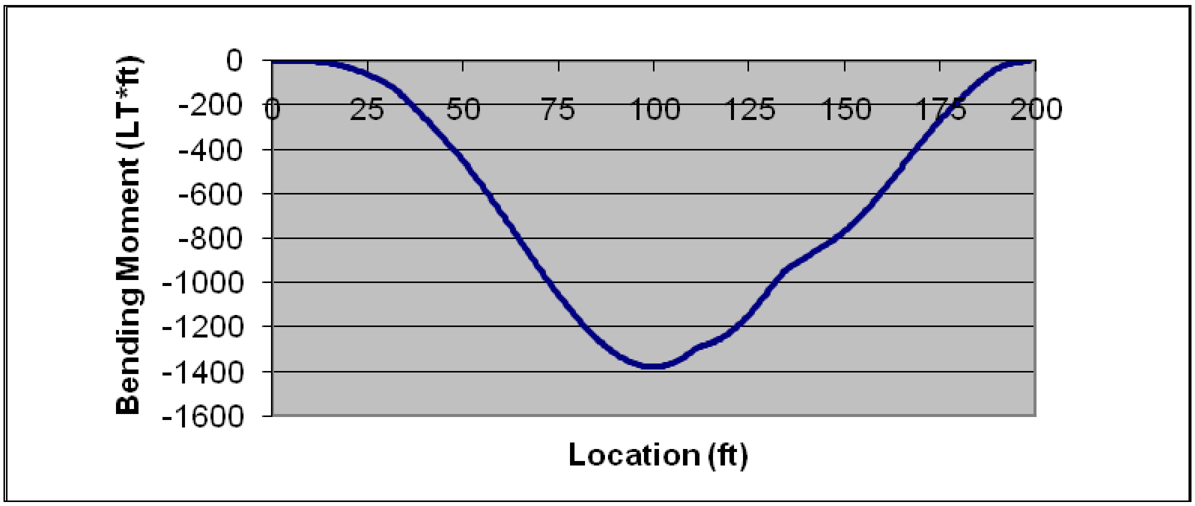


Figure 14: Still Water Bending Moments

The PlugNPlay code was modified so that hogging and sagging moments could be calculated for the PC-R using PlugNPlay and creating a waterplane representative of a wave with length equal to that of the ship. By doing this, it is clear the PlugNPlay can be updated to include hogging and sagging bending moments, and is recommended that the designers implement. The maximum hogging bending moment was 5,250 LT-ft.

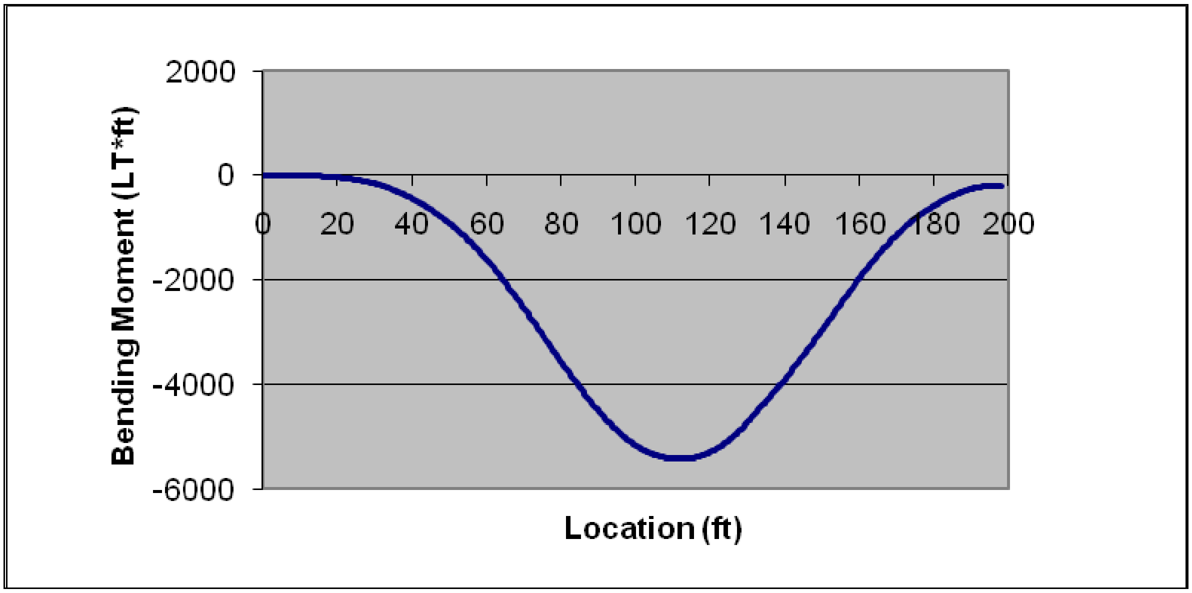


Figure 15: Hogging Bending Moment

Sagging bending moments were calculated in the same manner used for the hogging moment. The maximum sagging moment was calculated as 5,580 LT-ft. Being the largest of the three moments, this is the moment the structures were designed to support.

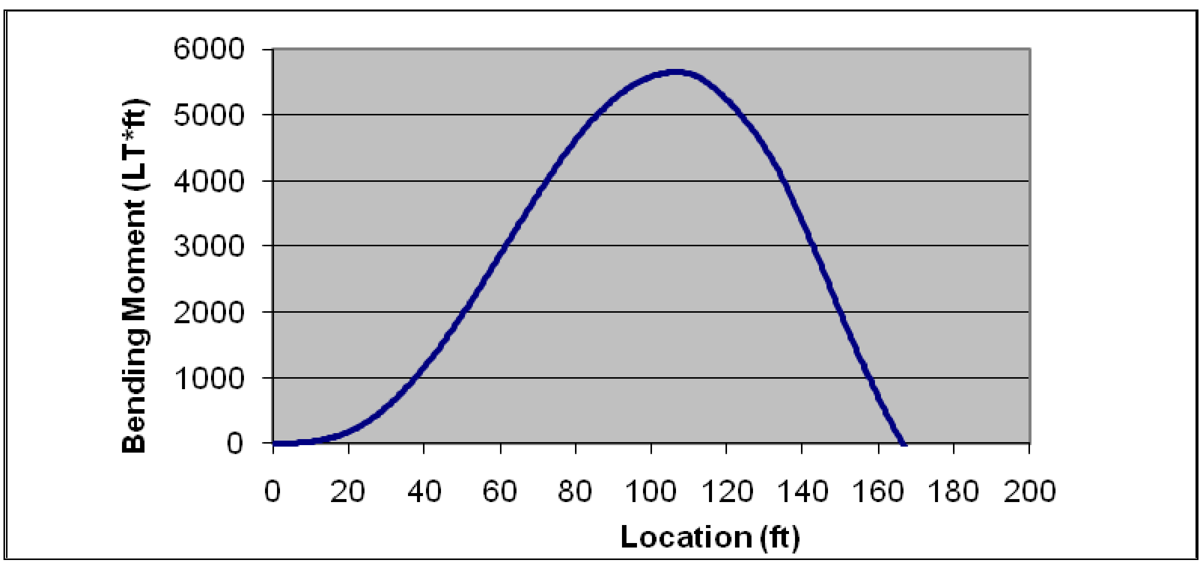


Figure 16: Sagging Bending Moment

Armament

The objective requirements for the PC-R contained many varied weapon systems. All threshold and most objective armament requirements were met. The ship has significant Anti-Submarine Warfare (ASW) capability. With hull mounted sonar under the bow and a towed array system at the stern, the PC-R has both active and passive surveillance. It also carries Common Very Light-Weight Torpedo (CVLWT) system. For Anti-Aircraft Warfare (AAW), there is a Phalanx Close-In Weapon System (CIWS) on top of the 02 level where there is the largest unobstructed view. There are also shoulder fired stinger missile launchers stored in lockers for use on the main deck or 01 level. The Surface Warfare (SUW) requirement is fulfilled by a 57 mm main gun at the bow, with the ability to fire 220 rounds per minute.

Other weapons on board the PC-R include 50 caliber machine guns, automatic grenade launchers, and M240B machine guns. A full list including quantity of each is listed in Table 7.

1 x MK 100 57 mm main gun
4 x 50 caliber machine guns
2 x MK 19 40 mm automatic grenade launchers
4 x M240B machine guns
6 x stinger missiles
1 x CWIS
Torpedoes

Table 7: PC-R Armament

The only objective requirements not reached were the 76 mm main gun, 8 Stand-Off Land Attack Missiles (SLAM), and the MK 41 Self-Defense Launching System (SDLS). These systems were deemed impractical for the size of the ship. For example, PlugNPlay allowed the team to place a 76 mm gun on the bow and see that gun required excessive weight and space, and was not necessary for the missions set forth.

Manning

The number of people needed to operate and maintain the various systems aboard the PC-R was estimated. The number of enlisted was based on the manning of the PC-14 and then increased based on increased complexity of the systems aboard the PC-R. The enlisted were broken down into departments: engineering, operations, control systems, and supply. A Chief Petty Officer was added for each department, and a Department Head was added for all but the supply team. The manning summary is shown in Table 8.

Position	Number	Breakdown
Officers	4	1 CO
		3 DH
Chief Petty Officers	4	1 per department
Enlisted	26	8 Engineers
		8 Operations
		8 Control Systems
		2 Supply
Detachment	6	
Total Manning	**40**	

Table 8: PC-R Manning

Although there was no detachment requirement for the PC-R, there is berthing and space for a detachment of six to account for service life manning growth or changes in mission.

General Arrangements

The general arrangements were created rapidly using PlugNPlay. PlugNPlay's ability to generate bending moments with each design change was of great benefit, because the heavy items were already placed before arrangements were created. Once the bending moments looked satisfactory, the general arrangements were created. Figure 17 shows the rough general arrangements created. The general arrangements were created by moving density solids for associated SWBS groups in Rhino, and then using PlugNPlay to quickly check the hydrostatics and bending moments. Many iterations of the general arrangements were completed in only a few hours. This is a significant benefit of PlugNPlay because traditional general arrangements can take a month given the complexity of some ships.

After each iteration, PlugNPlay was used to calculate the new hydrostatics. After the first iteration of general arrangements, trim was bow down. The pilot house, including the CIWS and mast, was shifted aft to achieve level trim. This was easily changed and PlugNPlay was used to calculate the new trim.

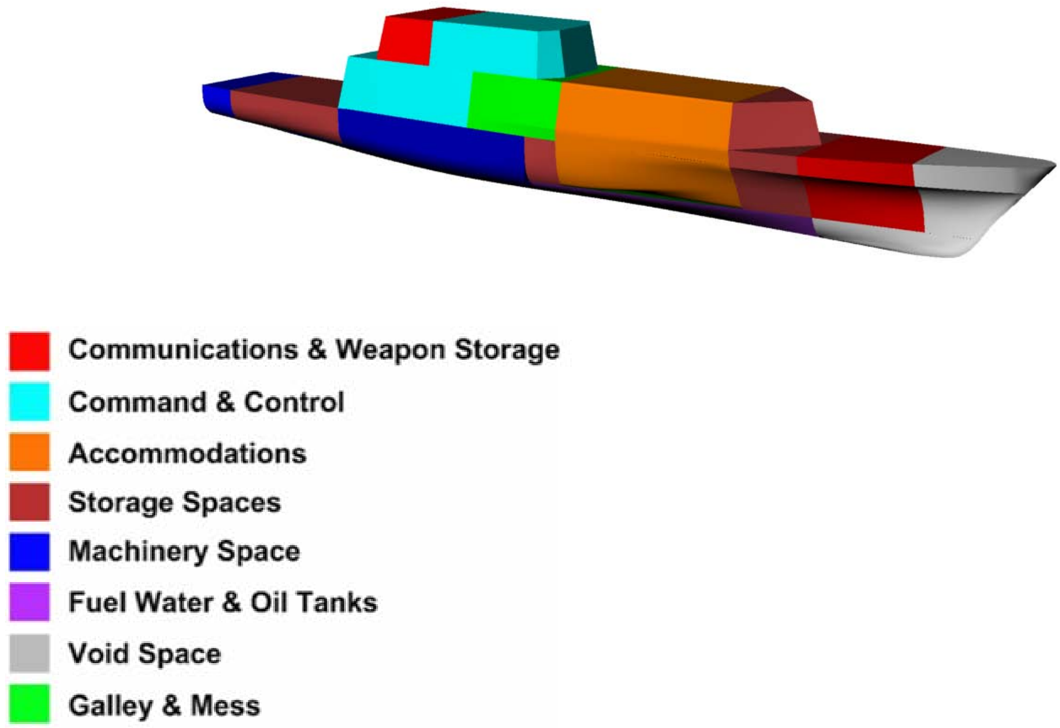


Figure 17: General Arrangements

The general arrangements were loosely based on existing patrol craft. The arrangements of the living spaces, galley, and mess are in the location with the largest volume that is not adjacent to the engine room. There is also virtually no distance between the mess and living spaces which adds convenience for the crew. The forward gun’s ammo storage is directly below allowing for convenient reloading. Storage spaces were added where needed. The aft storage space would typically consist of tools and spare parts for the diesel engines and maneuvering equipment, while the storage spaces more towards the bow include galley and closets for the living and common spaces. The locations of storage and mess were heavily influenced by personnel flow considerations. The fuel, water, and oil tanks were located in the remaining space below the lowest deck.

Stability

The PC-R intact and damaged stability were determined using hydrostatic parameters in Paramarine 7. PlugNPlay allowed the weights to be transferred easily to Paramarine which made the iterative process much faster when the arrangements needed to be adjusted. Figure 18 shows the GZ curve generated by Paramarine's stability tests. With an angle of vanishing stability over 100 degrees, the PC-R has good intact stability.

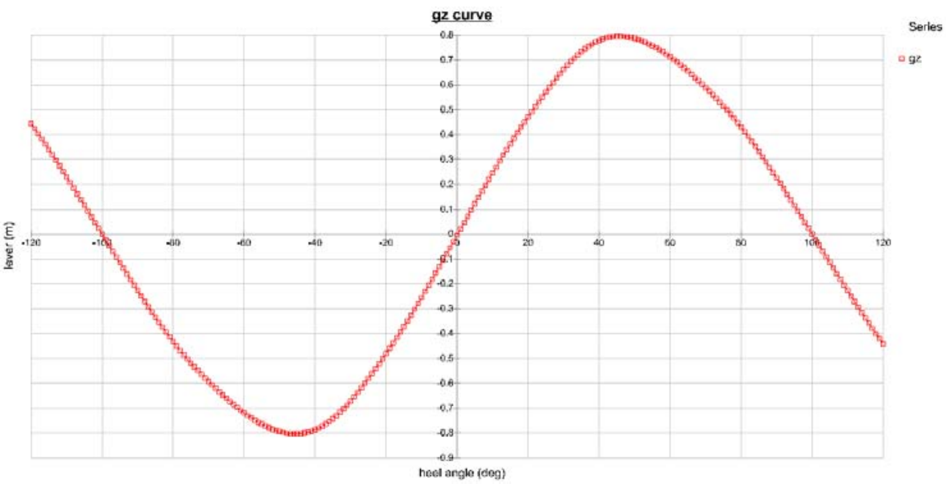


Figure 18: GZ Curve-Intact Stability

Two damage cases were considered when analyzing the PC-R's damaged stability. The first case considered was forward damage; the forward-most two sections between transverse bulkheads were flooded to represent a front end impact. The second case considered was aft damage; the two engine rooms were flooded. Figure 19 illustrates all flooded areas in the two damage cases considered.

Figure 19: Paramarine Damage Stability Model

In both damage cases the PC-R remains afloat. Figures 20 and 21 show the GZ curves generated by Paramarine's stability tests. The PC-R maintains good stability in both damage cases considered.

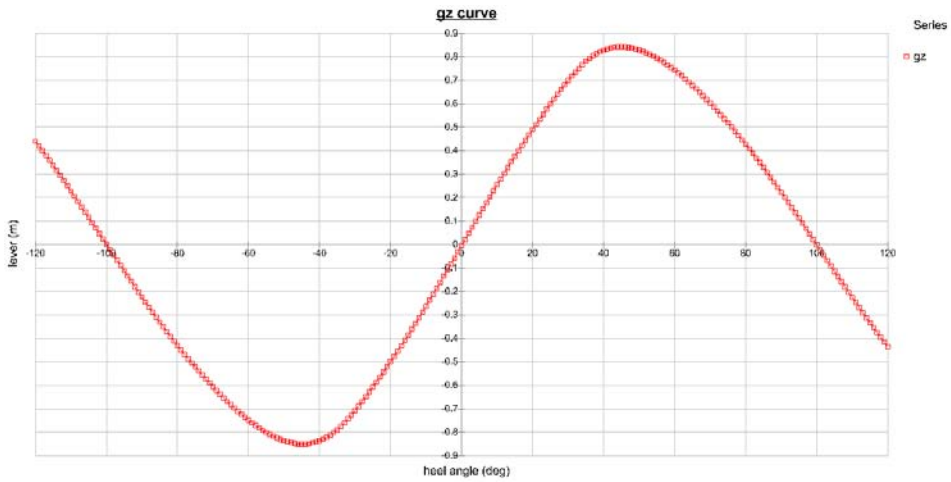


Figure 20: GZ Curve-Damage Forward

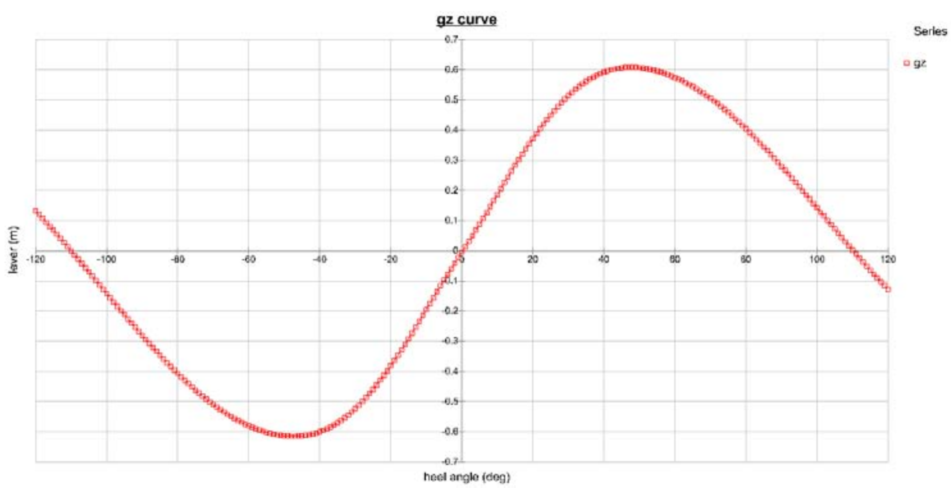


Figure 21: GZ Curve-Damage Aft

Seakeeping

The seakeeping analysis was performed using the Paramarine model created by PlugNPlay. The limiting criteria for personnel set forth were vertical acceleration less than 0.4 g, lateral acceleration less than 0.2 g, pitch angle less than 3 degrees, and roll angle less than 8 degrees. Upon running the seakeeping analysis in Paramarine, the prevalent limiting factor was revealed to be roll. The PC-R is operable at 12 knots at all headings in Sea State 3 (SS3). This meets the threshold requirement. SS4 was the objective. In SS4 at 12 knots, the PC-R was operable at all headings except beam seas where roll was 15 degrees. The roll angle plot for SS4 is shown in Figure 22. Because the hull is symmetrical, only headings of 0 through 180 degrees were calculated. The other half of the plot is a mirror image.

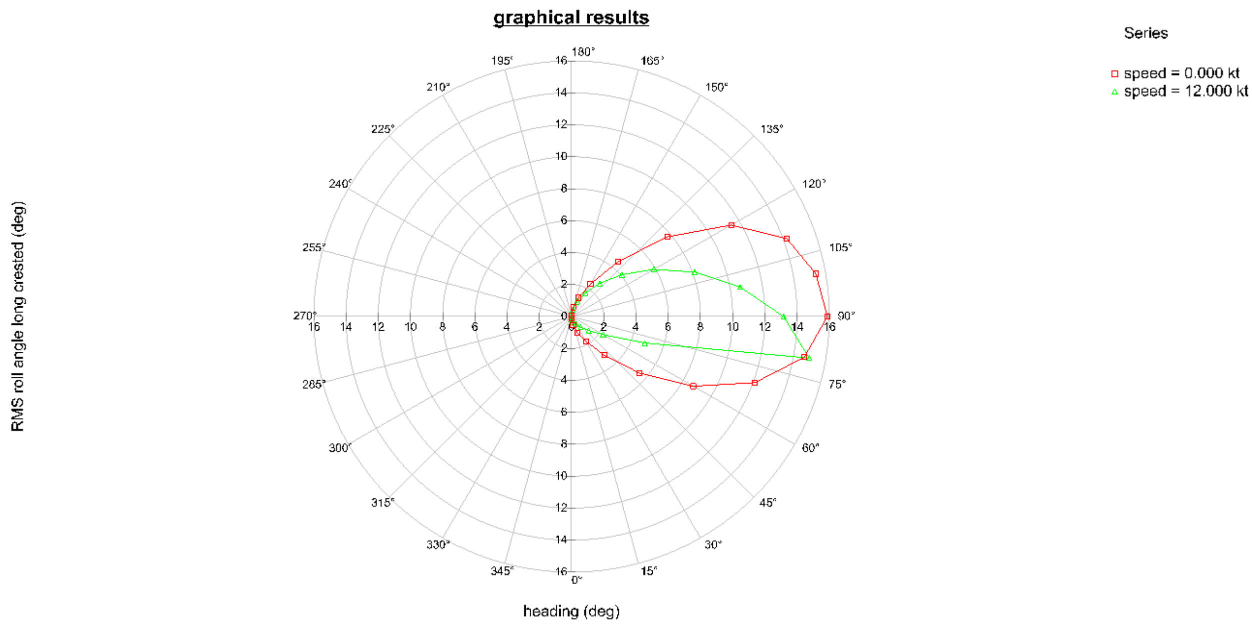


Figure 22: SS4 Plot

Structures

CISD is developing an interfacing between Design Program for Ship Structures (DPSS) and Rhino to design ship structures and create sectional drawings automatically. Bending moments, hull geometry, and principal dimensions for the PC-R design were used to produce a structural design with DPSS. The structure was designed using High-Strength Steel. The resulting midship structural drawing is shown in Figure 23.

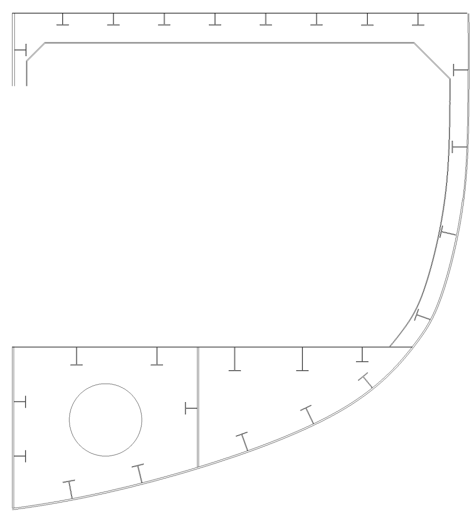


Figure 23: Midship Structural Drawing

The maximum shell thickness is half an inch and the main deck has a thickness of 0.125 inches. The inner bottom has a maximum thickness of 0.25 inches. The longitudinals are all common Navy tee sizes and shapes for producability.

Conclusions and Recommendations for Further Work

PC-R Concept

Concept Recommendations for Further Work

Specific communications and radar systems need to be selected for the PC-R. After all systems have been selected, more detailed general arrangements need to be performed. During the general arrangements, the living spaces will need to be more accurately sized as the current arrangements were done with order of magnitude estimates. Detailed arrangements will allow for a full test of PlugNPlay and more accurate results for weight summary, centers of gravity, seakeeping, stability, and structures. The stability results, while promising need to be assessed against a specific set of criteria.

Concept Conclusion

The PC-R meets all threshold requirements and multiple objective requirements. It is capable of transiting over 2,000 nm or sprinting at over 30 knots fully loaded. It is stable both intact and in simulated damage cases. There is sufficient area and volume to arrange the chosen systems as well as additional systems to be brought onboard in the future. Space was allotted for future detachment needs. The PC-R is a feasible patrol craft design, capable of interdiction, surveillance, and providing forward presence. It was designed to be easily produced and maintained, making it suitable for foreign export.

PlugNPlay

PlugNPlay Recommendations for Further Work

During the process of designing the PC-R using PlugNPlay methodology, a few issues arose that led to recommendations for the improvement of the software. During the PC-R's design, the majority of the components were researched and modeled. A more expansive model library will greatly facilitate future PlugNPlay designs.

Currently PlugNPlay only interfaces with Paramarine. It would be beneficial to interface PlugNPlay with other programs CISD already uses. For example, if resistance estimations were performed based off the hull already modeled in Rhino, it would save time. Another example is an interface to a weight estimation tool such as the regression based one used at CISD. This would provide weights for each SWBS group until specific components with attached weight information for a SWBS group are inserted into the PlugNPlay model.

Because PlugNPlay includes a CAD model of the hull, a PlugNPlay tool to automatically produce lines drawings is a feasible addition to PlugNPlay's capabilities. The user would input

the number of stations, waterlines, and buttock lines. The suggested tool would create hull lines by slicing the ship, compiling the cross-sections, and drawing axes. Such a tool would provide quick and accurate lines drawings.

Currently PlugNPlay can create still water bending moments and, with a little adjustment, would be capable of calculating moments for hogging and sagging conditions. Such a tool would eliminate the necessity of creating an additional model in another software program.

The final recommendation is to create further documentation and a tutorial for PlugNPlay. While some documentation for the naming conventions and model library of PlugNPlay exists, none exist for the use of the tools. Documentation for the inputs and outputs of each tool would allow less experienced PlugNPlay users to use the tools effectively. A tutorial that walks through the steps of the design process using PlugNPlay would help the user adjust to the new design methodology.

PlugNPlay Conclusion

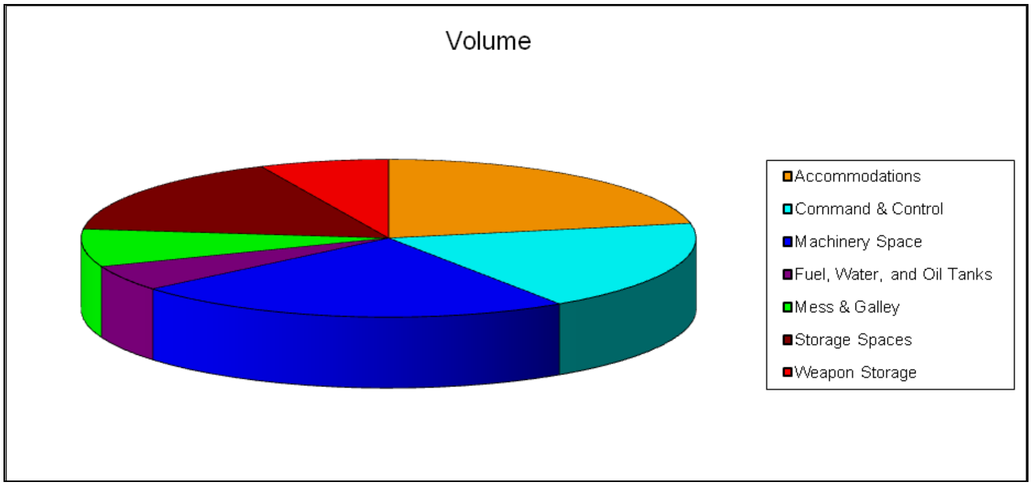
PlugNPlay is a useful tool for rapid concept ship design. It allows the user to make changes to their design and run the analyses again rapidly to see the effect of the adjustment. This saves a lot of time in the preliminary design stages and also allows the team to facilitate workload distribution. One team member could be working on machinery and electric loads, while another is adjusting the positions of the equipment and testing stability and bending moments. The ultimate benefit of PlugNPlay is the amount of time that will be saved and the quickness in which a concept design performed.

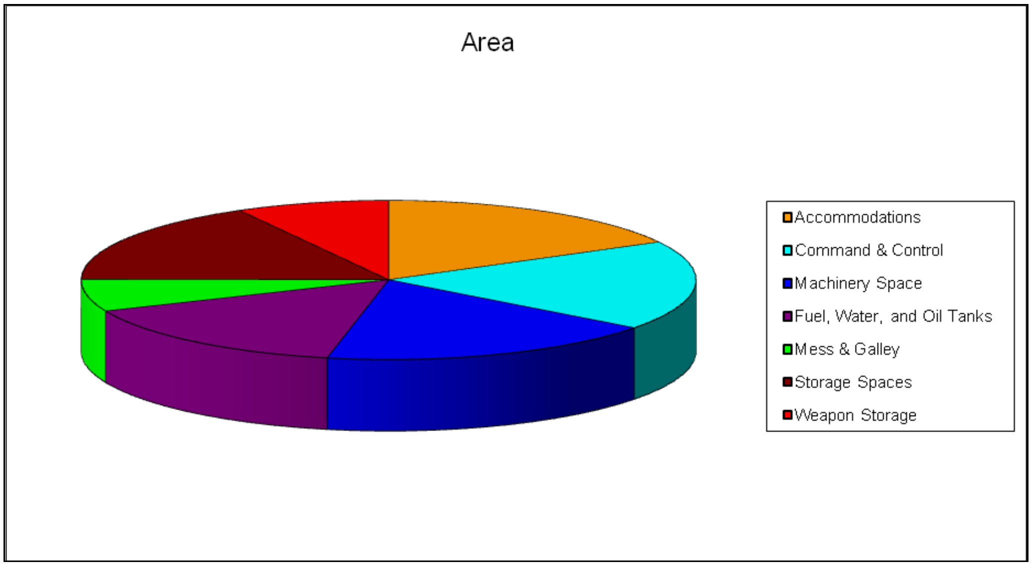
Appendix A - Weight Breakdown

		Count	CG x	CG y	CG z	Mass (kg)
SWBS 100	**HULL STRUCTURES**	**2**	**27.56**	**0.00**	**2.98**	**175661.25**
100	HULL STRUCTURES	1	27.57	0.00	2.91	174278.07
171	MASTS,TOWERS,TETRAPODS	1	25.79	-0.02	11.60	1383.18
SWBS 200	**PROPULSION PLANT**	**14**	**20.61**	**0.06**	**1.97**	**67862.29**
233	DIESEL ENGINES	4	22.78	-0.07	2.01	25304.05
240	TRANSMISSION+PROPULSOR SYSTEMS	1	11.35	0.00	2.06	12593.75
241	REDUCTION GEARS	2	16.75	-0.01	1.56	5350.74
243	SHAFTING	2	20.55	0.81	1.77	7040.33
245	PROPULSORS	2	2.63	0.00	-0.17	31.14
250	SUPPORT SYSTEMS	1	14.16	0.00	2.06	6886.47
260	PROPUL SUP SYS- FUEL, LUBE OIL	1	33.63	0.00	2.06	6358.08
290	SPECIAL PURPOSE SYSTEMS	1	31.20	0.00	2.06	4297.73
SWBS 300	**ELECTRIC PLANT, GENERAL**	**5**	**25.96**	**0.00**	**1.88**	**21237.18**
300	ELECTRIC PLANT, GENERAL	1	26.70	0.00	2.06	17173.97
311	SHIP SERVICE POWER GENERATION	4	22.83	-0.01	1.11	4063.20
SWBS 400	**COMMAND & CONTROL**	**2**	**23.77**	**0.36**	**5.86**	**21596.16**
400	COMMAND & CONTROL	1	30.25	0.00	6.07	16590.41
462	PASSIVE SONAR	1	2.27	1.54	5.20	5005.75
SWBS 500	**AUXILIARY SYSTEMS, GENERAL**	**2**	**24.78**	**-0.31**	**2.57**	**51086.06**
500	AUXILIARY SYSTEMS, GENERAL	1	28.22	0.00	2.06	43182.79
583	BOATS,HANDLING+STOWAGE SYSTEMS	1	5.96	-2.01	5.37	7903.26
SWBS 600	**OUTFIT+FURNISHING,GENERAL**	**1**	**28.25**	**0.00**	**2.06**	**36687.74**
600	OUTFIT+FURNISHING,GENERAL	1	28.25	0.00	2.06	36687.74
SWBS 700	**ARMAMENT**	**9**	**34.68**	**0.02**	**7.88**	**15792.95**
711	GUNS	3	36.87	0.02	8.77	13691.82
713	AMMUNITION STOWAGE	1	20.42	0.00	2.06	1218.81
721	LAUNCHING DEVICES	4	24.42	0.01	7.84	0.04
760	SMALL ARMS+PYROTECHNICS	1	20.42	0.00	2.06	882.28
--	**DEADWEIGHT**	**1**	**23.17**	**0.00**	**2.06**	**91429.54**
--	**Margins**	**1**	**28.25**	**0.00**	**2.06**	**40448.42**
	Cumulative		**25.71**	**-0.01**	**2.74**	**521801.59**

Appendix B – Area and Volume Breakdowns

Arrangements	**Area [%]**	**Volume [%]**
Accommodations	17%	22%
Command & Control	18%	19%
Machinery Space	18%	23%
Fuel, Water, and Oil Tanks	15%	5%
Mess & Galley	6%	8%
Storage Spaces	17%	16%
Weapon Storage	8%	7%





Appendix C - Study Guide

Patrol Craft Replacement

Introduction

US Navy recently recalled the Cyclone patrol craft due to fatigue issues. The Cyclone class is the US Navy's only patrol craft. The US Navy now relies upon larger assets such as frigates and destroyers to fill this void. This is rarely an optimal use of assets as the vessels are often far more capable than the patrol missions require and cost more to operate.

The African Partnership Station allows the US to help African nations to patrol their own waters and enforce regional and international laws. In the past the US Navy has sent DDGs, CGs, HSVs, and LSDs to train African navies and coast guards. These high value assets are not suitable for this mission as they are needed elsewhere and are inappropriate to train on, because African nations will not be employing such vessels. A smaller patrol craft would allow the US Navy to train foreign navies on appropriately capable ships. These patrol craft would also be affordable enough that the US could sell them or supply them as foreign aid.

CISD has developed a concept design methodology and tool set dubbed PlugNPlay Design which needs evaluation and refinement. Designing a relatively simple craft such as the Patrol Craft Replacement will be a good test of the methodology and tools.

Aim

To design a Patrol Craft Replacement to provide a forward presence and theatre security cooperation circa 2020 with the aim for the vessel to be designed for foreign export.

To identify technical issues and requirements associated with that design requiring further investigation and development.

To evaluate PlugNPlay Design and identify areas for improvement.

Ship Design Requirements

The vessel shall be capable of undertaking the following missions:

Forward Presence-patrol in international waters, transit foreign coastal zones, and conduct foreign port visits

Theater Security Cooperation- all tasks outlined in Forward Presence with an emphasis on building partnerships by training allies

The ship design shall meet the specific requirements detailed.

Areas of Technology Exploration

Design features that allow for high maintainability and producibility.

Constraints

The design team shall use PlugNPlay Design.

The report and design shall be unclassified.

Approach

The team should research the range of flexible mission packages and equipment required to be operated on and from the vessel concept.

The team will review requirements and then brainstorm potential ideas.

Suitable ideas shall be assessed for compliance against key requirements, its ability to maximize overall flexibility in its role and its overall technical feasibility.

The competing ideas shall be reduced to a preferred design concept using a decision making process.

A balanced design shall result with performance analyses and concepts developed.

The implications of any new technology or operational issues shall be noted. Recommendations for follow on work shall be developed.

The impact of PlugNPlay Design on the design process shall be analyzed and recorded. Suggestions for further development of PlugNPlay Design shall be noted.

Deliverables

All work will be documented in a CISD Project Technical Report. The final report and presentation shall be suitable for unclassified, public release.

During the first 2 weeks the team will produce a team project plan of actions, assignments and milestones to be presented to CISD leadership for approval. During the project this plan shall be maintained.

The team will develop and give informal intermediate presentations and a final project presentation.

The resulting ship design shall be detailed including:

Summary of characteristics (L, B, T, Installed Power, etc.)

Documented decision making process

Estimated performance with operational profile

Comprehensive SWBS breakdown

Electrical Loads Summary

Hullform lines drawing

Speed/Power Curve

Bending Moments

Intact and Damage Stability (GZ curves, Hydrostatics)

Seakeeping (RAOs etc.)

Full general arrangement drawing

Area/Volume Report

Midship Structural Drawing

Machinery List

A brief summary of PlugNPlay Design’s affect on the project to be recorded and informally presented.

Patrol Craft Replacement Statement of Requirements.

PC-R Specifications		
	Threshold	**Objective**
Range	2,000 nm	3,500 nm
Max Speed	24 kts	36 kts
Flight Deck	none	VERTREP
Boat Handling	7 m RHIB equivalent L&R	11 m RHIB equivalent L&R w/ support facility
AAW	Stinger Missile	CIWS & Mk 41 Self Defense Launching System
ASW	none	hull mounted sonar, towed array, & Common Very Light Weight Torpedoes
SUW	40 mm main gun	76 mm main gun, 8 Stand-Off Land Attack Missiles
Sea State Operability	SS3	SS4
Sea State Survivability	SS5	SS6
Berthing	25	45
Displacement	250-700 tons	